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A DATA REDUCTION TECHNIQUE FOR METEOROLOGICAL WIND DATA ABOVE 30 KILOMETERS

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ECOM
UNITED STATES ARMY ELECTRONICS COMMAND

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ABSTRACT

The FPS-16 tracking systems superimpose undesired oscillations on the real position data resulting in rapidly fluctuating successive position points which are physically unrealistic. A linear digital filter of the form $\overline{Q}_K = \sum_{M=-58}^{M=58} W_M Q_{K+M}$ is applied separately to each component to smooth the data. The frequency response is given and the data are corrected by a method derived by Eddy et al. (1965). Undesired high frequency oscillations are effectively eliminated and successive wind profiles show good continuity.

CONTENTS

INTRODUCTION

Atmospheric temperature, pressure, density, and wind data, derived from meteorological rocket soundings are used in meteorological research and for military projects requiring a knowledge of stratospheric behavior. Detailed wind profiles are often required for computing trajectories for ballistic rockets. This paper will describe the filtering and correction techniques used to derive winds from an FPS-16 radar track of a falling object.

FILTERING TECHNIQUE

Wind data derived from radar tracks of parachutes and spheres falling through the atmosphere are used as meteorological support data by several projects at White Sands Missile Range, New Mexico.

An FPS-16 radar tracks the sensor and records its position relative to the radar on a magnetic tape at the rate of twenty points per second. The meteorological wind reduction technique, however, uses only every other point, or ten points per second. These position points are specified by time and three space coordinates (slant range, azimuth angle, and elevation angle). A correction for refraction and earth curvature is then applied to the position points. A typical wind profile consists of about 18,000 data points and yields wind data from 25 km to about 65 km.

As is true with any tracking system, the system itself superimposes undesired oscillations (noise) on the real position data resulting in rapidly fluctuating successive position points which are physically unrealistic. To help compensate for this feature a linear digital filter, eq (1), in the form of a weighted running average over 117 points *(11.7 seconds) is applied separately to each component (slant range, azimuth angle, and elevation angle).

$$\overline{Q}_K = \sum_{M=-58}^{M=58} W_M Q_{K+M}, \qquad (1)$$

where W_M is the value of the Mth weight, Q_{K+M} is the (K+M)th unsmoothed value of a coordinate, and $\overline{Q}_K$ is the Kth smoothed value of the coordinate. The weights are symmetrically centered about $W_o (W_N = W_{-N})$ and are shown in Figure 1. Assuming the unsmoothed coordinate values may be represented by a sum of sinusoidal oscillations of various amplitudes, phases, and frequencies, a frequency response (ratio of the amplitude of a sinusoidal wave in

* Table 1 shows the coefficients for the 117-point symmetrical filter.

TABLE 1

COEFFICIENTS FOR THE 117-POINT SYMMETRICAL FILTER.

WGT(0) = 0.35708064E-01	WGT(30) = -0.10131001E-02
WGT(1) = 0.35636344E-01	WGT(31) = -0.14721988E-02
WGT(2) = 0.35272675E-01	WGT(32) = -0.19144034E-02
WGT(3) = 0.34784139E-01	WGT(33) = -0.21881496E-02
WGT(4) = 0.34025734E-01	WGT(34) = -0.24564068E-02
WGT(5) = 0.33167716E-01	WGT(35) = -0.25690121E-02
WGT(6) = 0.32067885E-01	WGT(36) = -0.26900660E-02
WGT(7) = 0.30898912E-01	WGT(37) = -0.26702617E-02
WGT(8) = 0.29520595E-01	WGT(38) = -0.26742817E-02
WGT(9) = 0.28107178E-01	WGT(39) = -0.25531311E-02
WGT(10)= 0.26519604E-01	WGT(40) = -0.24715428E-02
WGT(11)= 0.24932820E-01	WGT(41) = -0.22803228E-02
WGT(12)= 0.23208045E-01	WGT(42) = -0.21437710E-02
WGT(13)= 0.21520080E-01	WGT(43) = -0.19120444E-02
WGT(14)= 0.19729587E-01	WGT(44) = -0.17486000E-02
WGT(15)= 0.18010426E-01	WGT(45) = -0.15025814E-02
WGT(16)= 0.16221950E-01	WGT(46) = -0.13362864E-02
WGT(17)= 0.14536376E-01	WGT(47) = -0.10975813E-02
WGT(18)= 0.12811107E-01	WGT(48) = -0.94739597E-03
WGT(19)= 0.11216145E-01	WGT(49) = -0.73216618E-03
WGT(20)= 0.96064442E-02	WGT(50) = -0.61135714E-03
WGT(21)= 0.81493637E-02	WGT(51) = -0.42993361E-03
WGT(22)= 0.66970661E-02	WGT(52) = -0.34591034E-03
WGT(23)= 0.54140097E-02	WGT(53) = -0.20284763E-03
WGT(24)= 0.41493890E-02	WGT(54) = -0.15742585E-03
WGT(25)= 0.30646684E-02	WGT(55) = -0.51962753E-04
WGT(26)= 0.20060650E-02	WGT(56) = -0.42007490E-04
WGT(27)= 0.11321195E-02	WGT(57) = 0.31125163E-04
WGT(28)= 0.28621851E-03	WGT(58) = 0.12746845E-04
WGT(29)= -0.37580166E-03	

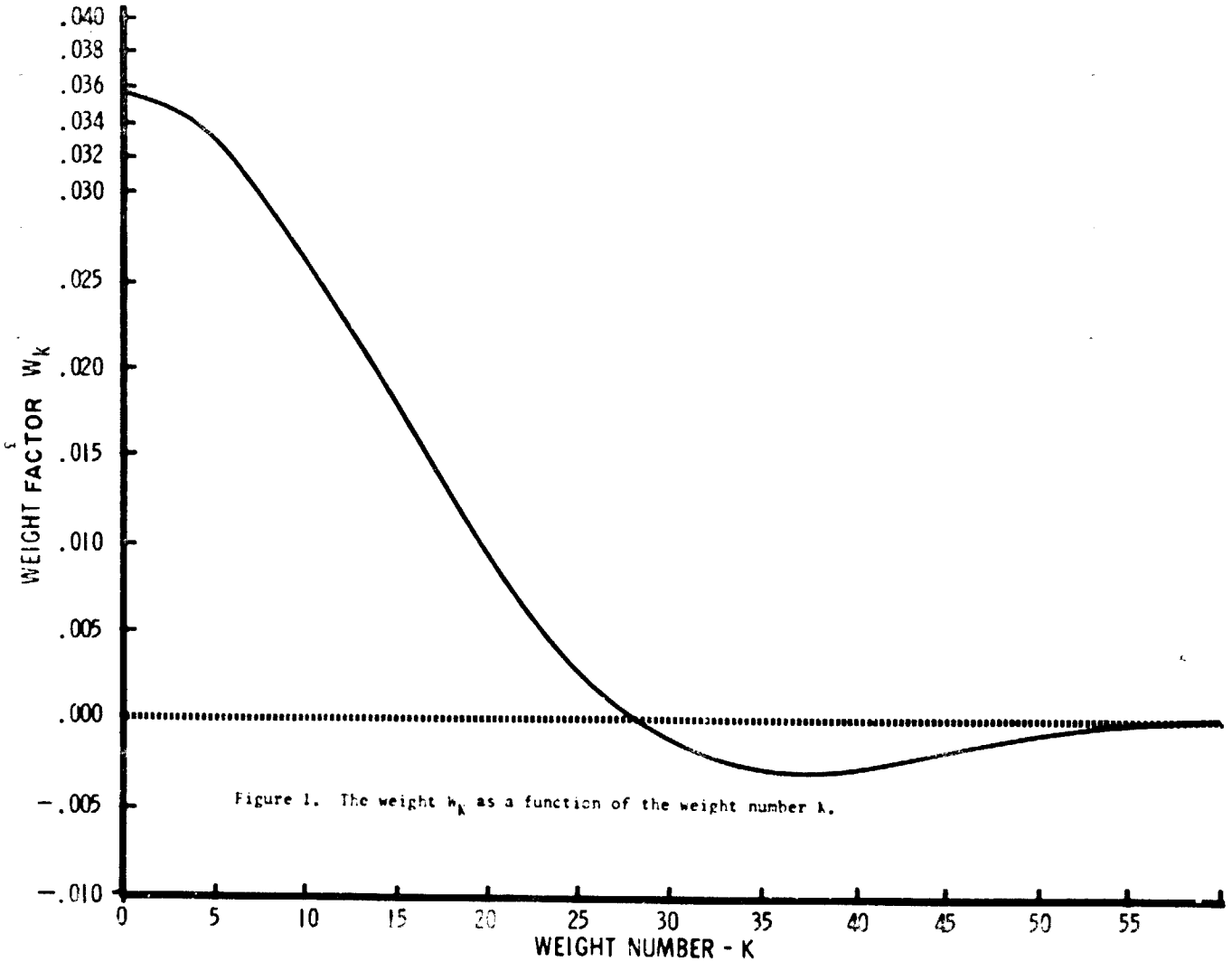

Figure 1. The weight w_k as a function of the weight number k.

the smoothed data to the amplitude of the same wave in the unsmoothed data) may be calculated, eq (2). This will give the effect of the filter on the data.

$$R(f) = \sum_{M=-58}^{M=58} W_M \cos\left(\frac{\pi f M}{5}\right) \text{ for } 0 \leq f \leq 5 \text{ sec}^{-1}, \quad (2)$$

where R(f) is the frequency response at frequency f. The frequency response of this filter is shown in Figure 2. The filter essentially eliminates oscillations which have frequencies greater than 0.3 sec^{-1} (periods less than three seconds). Figures 3, 4, and 5 show typical samples of the first differences in the smoothed and unsmoothed values of slant range, azimuth, and elevation angles at increments of 0.1 second.

The first and second derivatives of each coordinate are approximated by equations (3) and (4).

$$\dot{\bar{Q}}_K = 5(\bar{Q}_{K+1} - \bar{Q}_{K-1}), \quad (3)$$

$$\ddot{\bar{Q}}_K = 100(\bar{Q}_{K+1} - 2\bar{Q}_K + \bar{Q}_{K-1}), \quad (4)$$

where $\bar{Q}_K$, $\dot{\bar{Q}}_K$, and $\ddot{\bar{Q}}_K$ are the Kth values of the smoothed coordinate and its first and second derivatives, respectively. A transformation of coordinates is performed which gives position, velocity, and acceleration data in terms of components oriented north-south (y), east-west (x), and normal to the surface of the earth (z). The acceleration values of each component fluctuate excessively and are physically unacceptable. Ten weights are used to filter these data and are derived from equation (5),

$$\ddot{\bar{A}}_K = \sum_{M=0}^{9} W_M^* \ddot{A}_{K-10M}, \quad (5)$$

where $\ddot{\bar{A}}_K$ is the Kth value of the smoothed acceleration data, W_M^* the Mth weight, and $\ddot{A}_{K-10M}$ the (K-10M)th value of the unsmoothed acceleration data of one of the components*. Unsmoothed values one second apart instead of a tenth of a second apart are used in the smoothing. The amplitude of the frequency response may be calculated from equations (6), (7), and (8).

$$|R^*(f)| = (C[f]^2 + S[f]^2)^{1/2}, \quad (6)$$

$$C(f) = \sum_{M=0}^{9} W_M^* \cos(2\pi f M), \quad (7)$$

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* Table 2 shows the coefficients for the 10-point non-symmetrical filter.

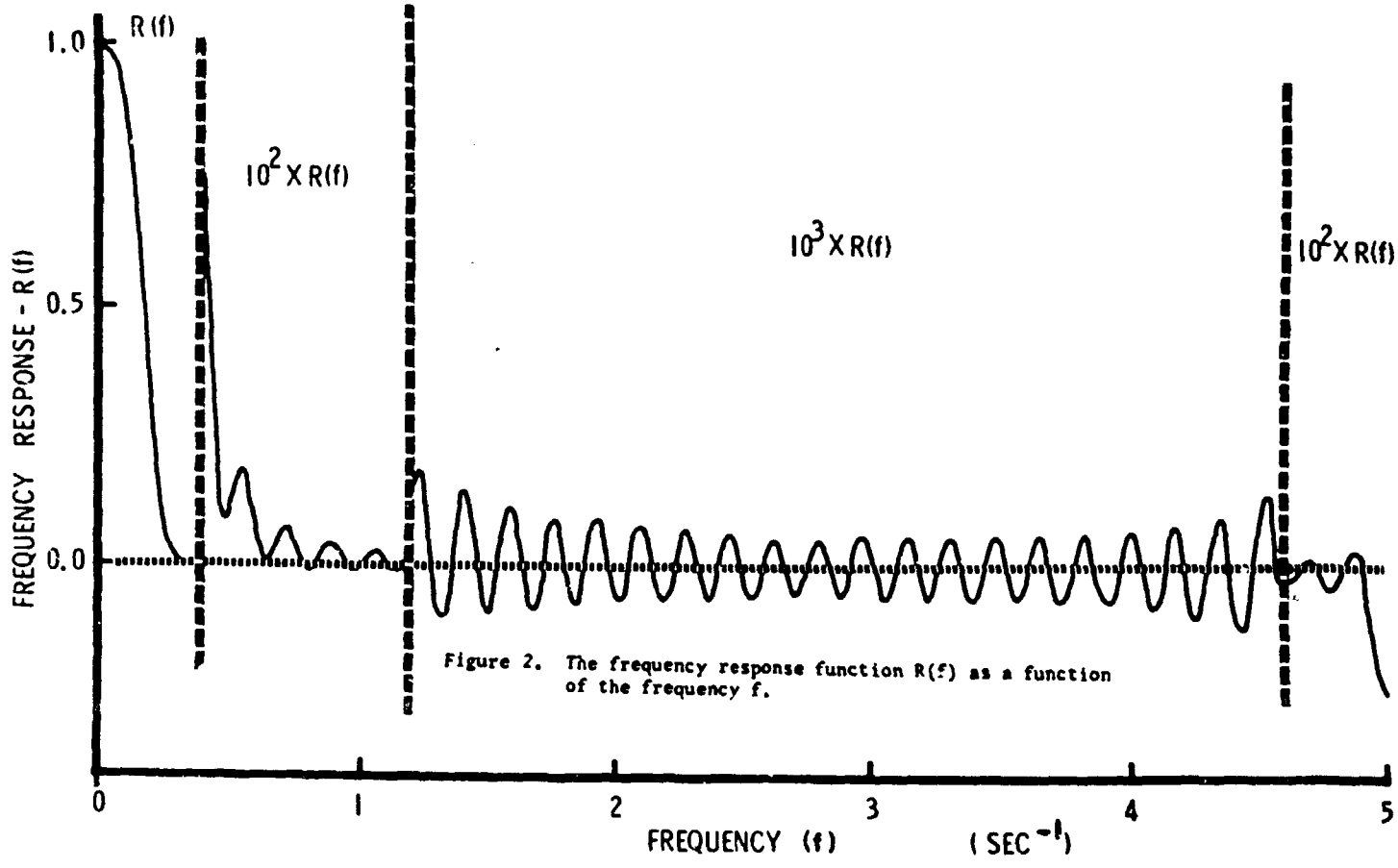

Figure 2. The frequency response function R(f) as a function of the frequency f.

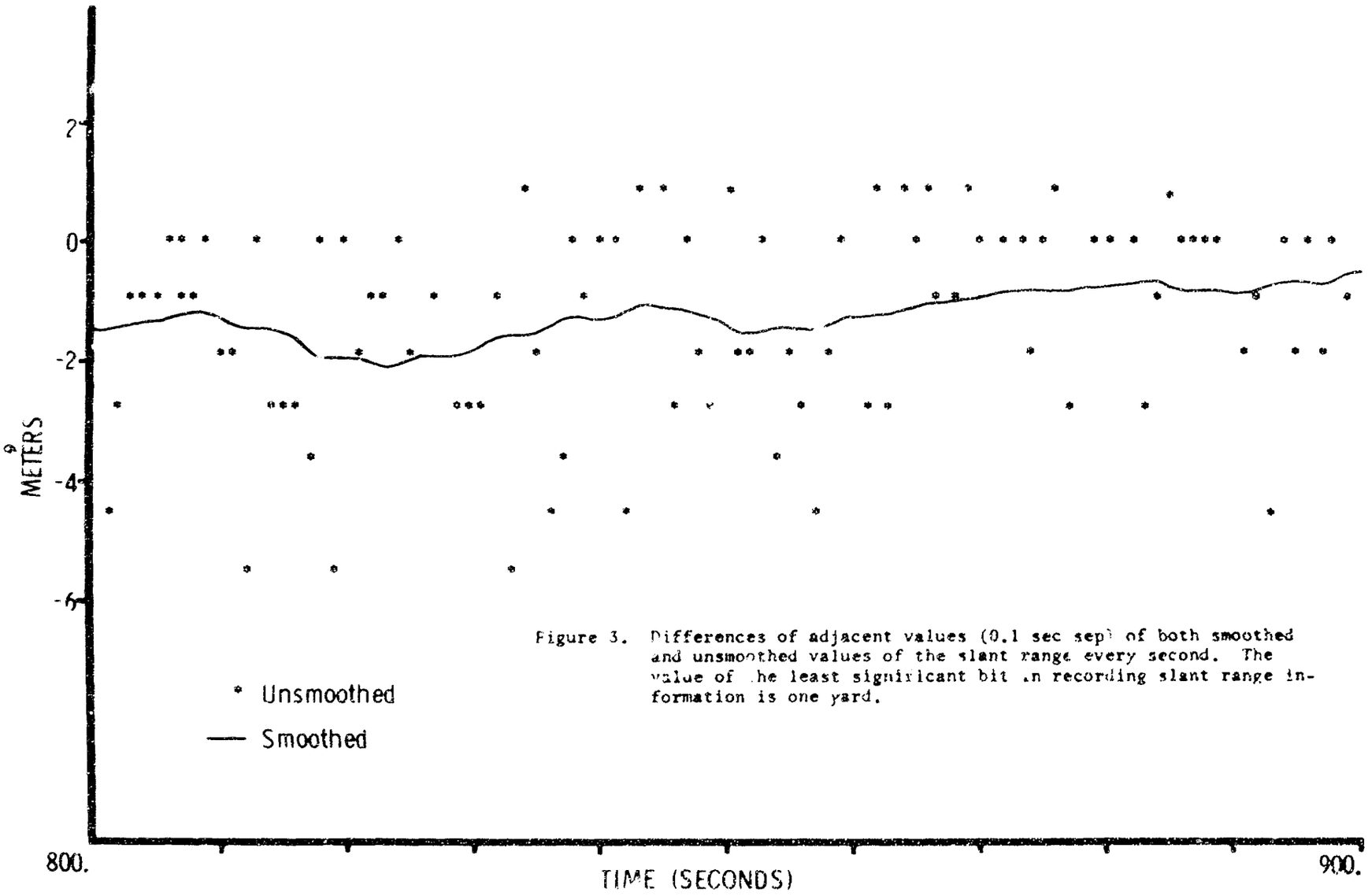

Figure 3. Differences of adjacent values (0.1 sec sep) of both smoothed and unsmoothed values of the slant range every second. The value of the least significant bit in recording slant range information is one yard.

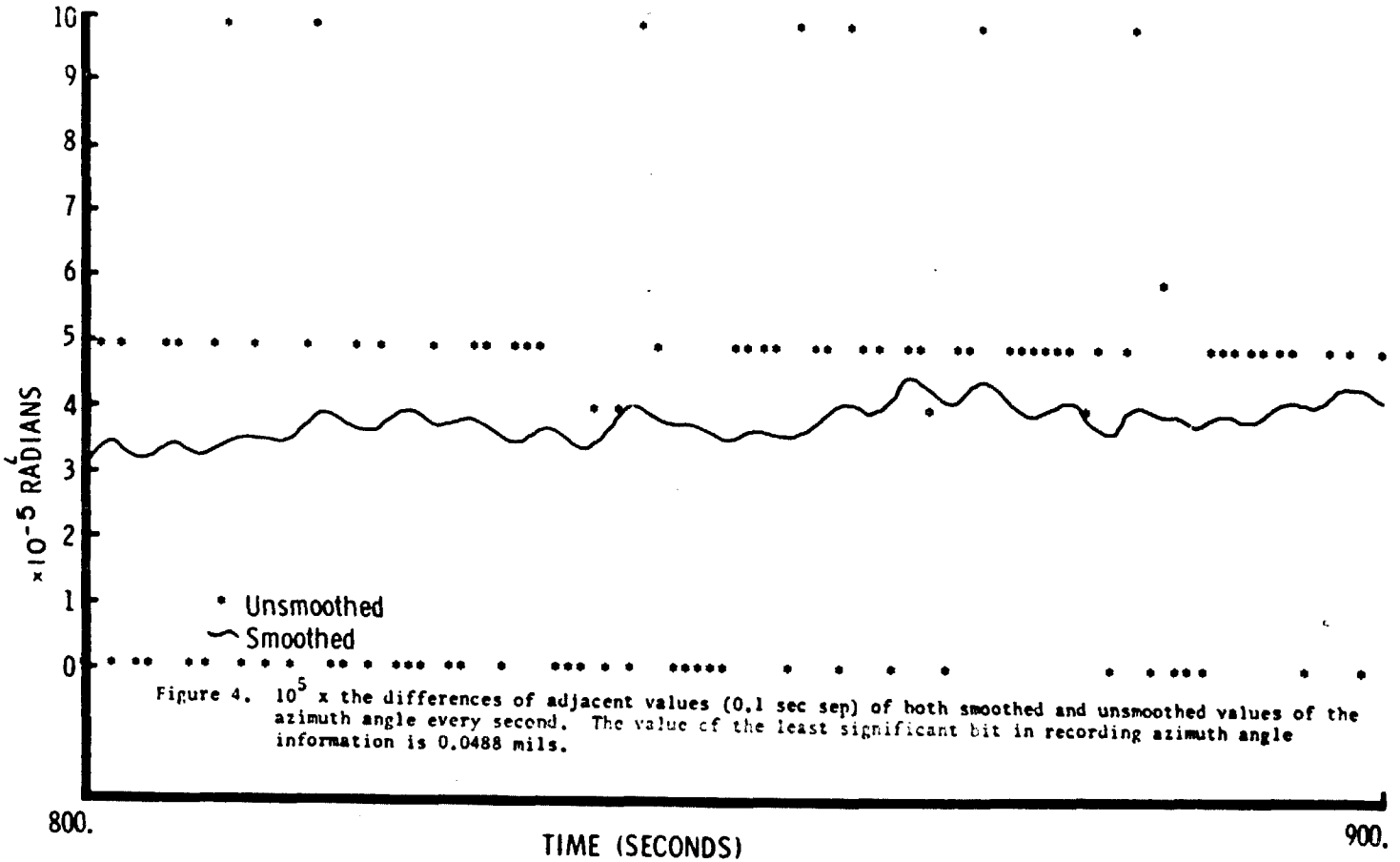

Figure 4. 10^5 x the differences of adjacent values (0.1 sec sep) of both smoothed and unsmoothed values of the azimuth angle every second. The value of the least significant bit in recording azimuth angle information is 0.0488 mils.

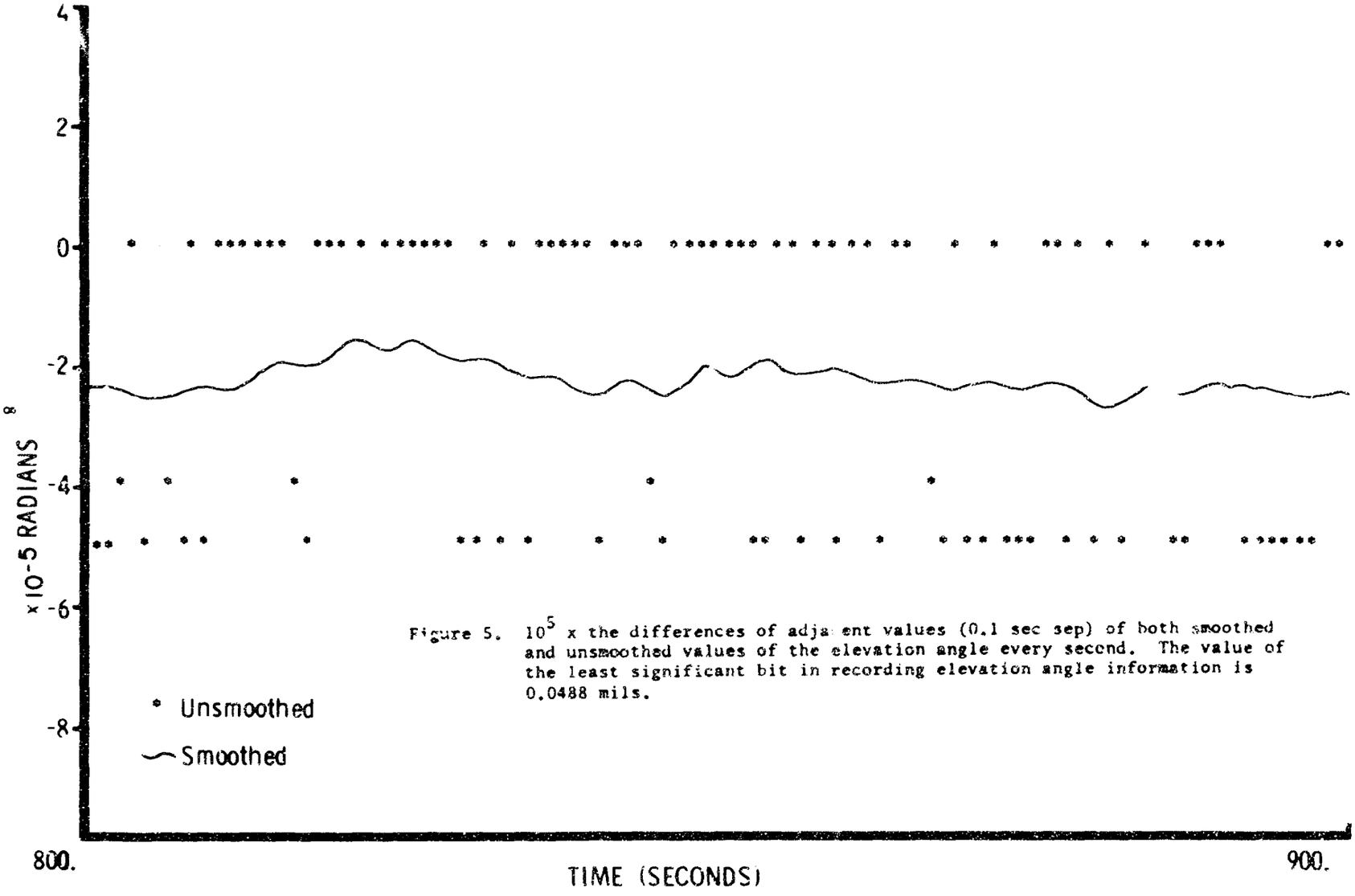

Figure 5. 10^5 x the differences of adjacent values (0.1 sec sep) of both smoothed and unsmoothed values of the elevation angle every second. The value of the least significant bit in recording elevation angle information is 0.0488 mils.

TABLE 2

COEFFICIENTS FOR THE 10-POINT NON-SYMMETRICAL FILTER

WGT(0) = 0.93263928E-01
WGT(1) = 0.10963999E 00
WGT(2) = 0.12145806E 00
WGT(3) = 0.12780346E 00
WGT(4) = 0.12803132E 00
WGT(5) = 0.12177899E 00
WGT(6) = 0.10896906E 00
WGT(7) = 0.89803061E-01
WGT(8) = 0.64746658E-01
WGT(9) = 0.34506476E-01

$$S(f) = \sum_{M=0}^{9} W_M^* \sin(2\pi f M) \qquad (8)$$

for $0 \leq f \leq 0.5$ sec^{-1} where $|R^*(f)|$ is the magnitude of the frequency response at frequency f. The weights are shown in Figure 6 and $|R^*(f)|$ in Figure 7.

CORRECTION TECHNIQUE

Another error of the system must be corrected, namely the sensor's ability to respond to the actual wind. The faster the sensor falls, the less likely it will respond to the actual wind. In other words, small-scale wind oscillations will have little effect on the sensor while those with longer periods will be observed with greater accuracy. Therefore, the wind sensor itself becomes a time varying filter applied to the wind data. Eddy et al. (1965) designed a correction technique which theoretically eliminates this effect, eq (9).

$$\dot{\bar{X}}_K = \dot{X}_K - \frac{\ddot{X}_K \dot{Z}_K}{\ddot{Z}_K + g} \quad , \qquad (9)$$

where $\dot{\bar{X}}_K$, $\dot{X}_K$, $\ddot{X}_K$, $\dot{Z}_K$, and $\ddot{Z}_K$ are the Kth values of the east-west wind component, sensor velocity, sensor acceleration, sensor vertical velocity, and sensor vertical acceleration, respectively, and g the gravity constant. An analogous equation is also applied to the north-south component. $\dot{\bar{Z}}_K$ is always assumed to be zero. This correction technique has been experimentally verified by Kays and Olsen (1966). Typical north-south and east-west wind component profiles in final filtered and corrected form are shown in Figure 8.

CONCLUSION

The wind reduction technique discussed is most applicable when the sensor is a point source and is tracked by a radar capable of at least a ten points per second sampling rate. Undesired high frequency oscillations are effectively eliminated, and successive wind profiles show good continuity. This technique is currently used at White Sands Missile Range, New Mexico, by the Atmospheric Sciences Laboratory.

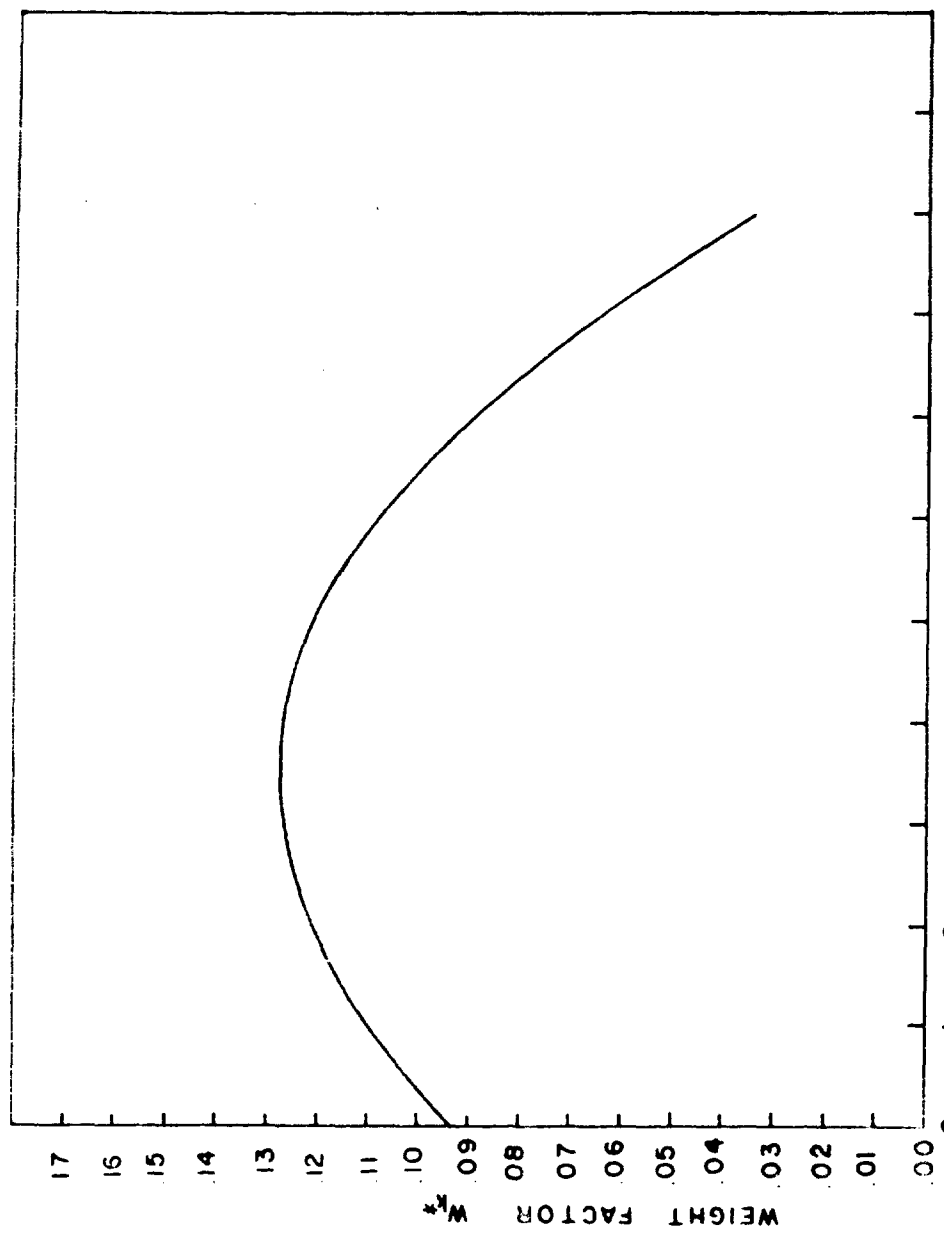

Figure 6. The weight h_k^* as a function of the weight number k.

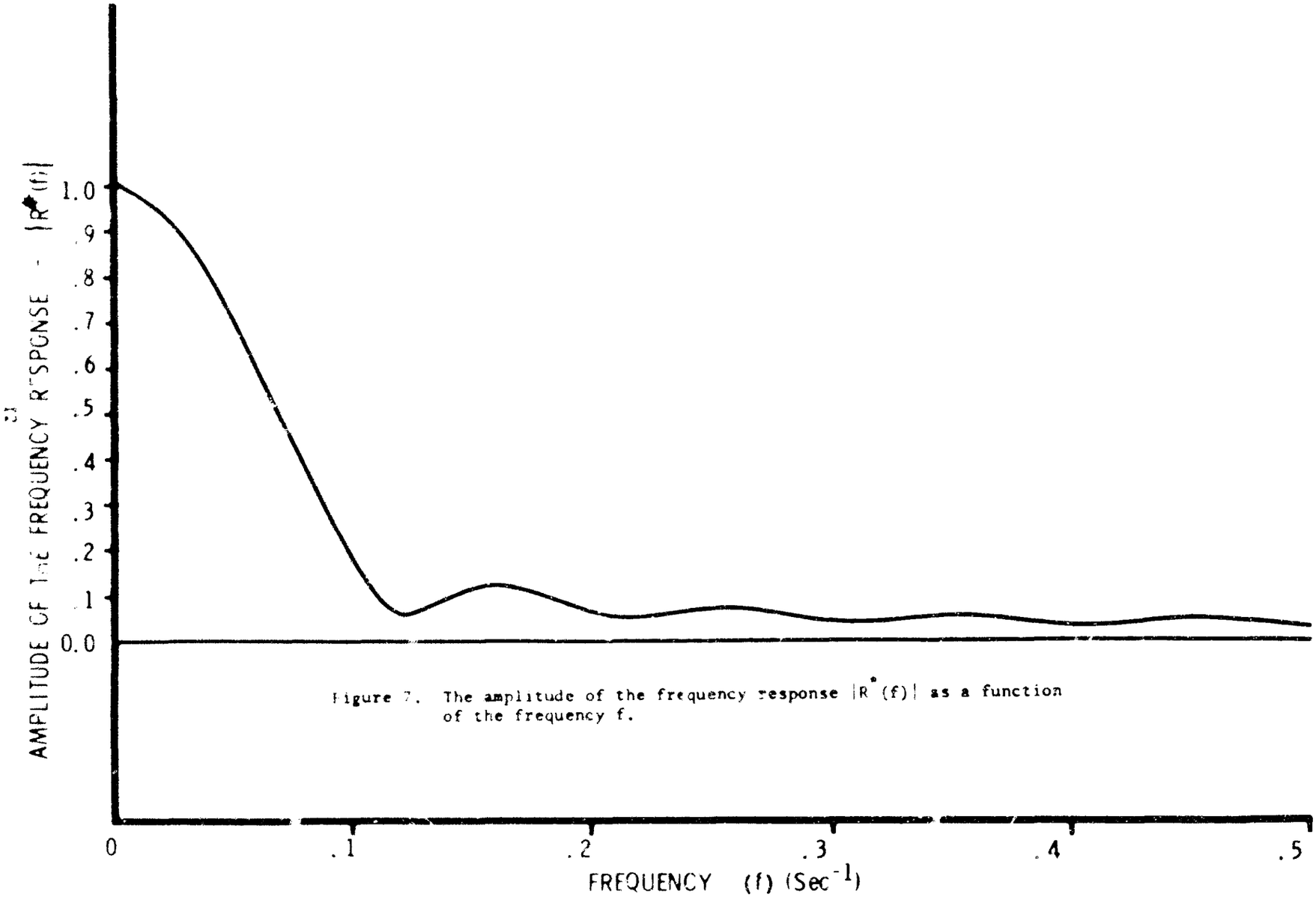

Figure 7. The amplitude of the frequency response $|R^*(f)|$ as a function of the frequency f.

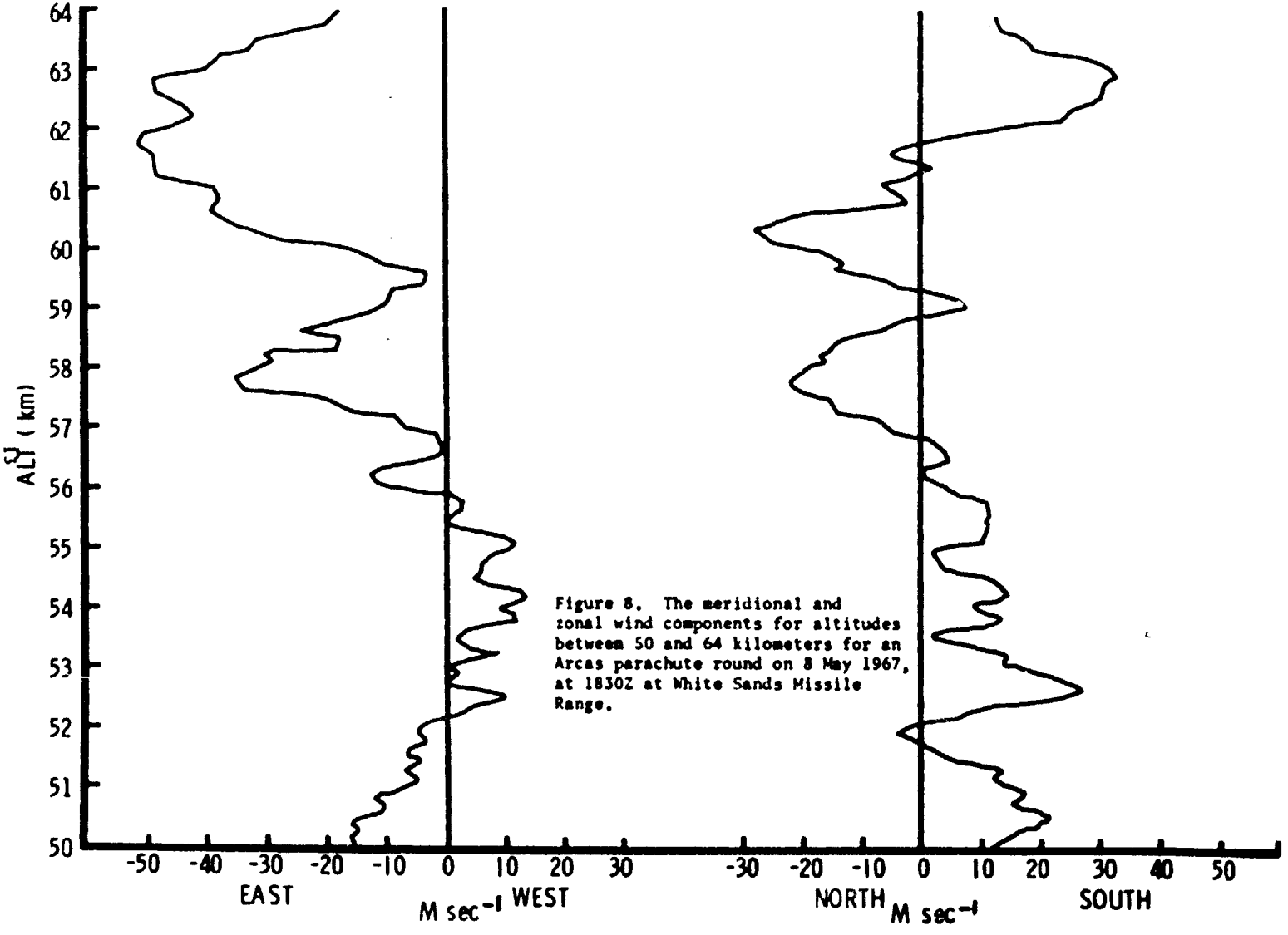

Figure 8. The meridional and zonal wind components for altitudes between 50 and 64 kilometers for an Arcas parachute round on 8 May 1967, at 18302 at White Sands Missile Range.

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13. ABSTRACT

The FPS-16 tracking systems superimpose undesired oscillations on the real position data resulting in rapidly fluctuating successive position points which are physically unrealistic. A linear digital filter of the form

$$\overline{Q}_K = \sum_{M=-58}^{M=58} W_M Q_{K+M}$$

is applied separately to each component to smooth the data. The frequency response is given and the data are corrected by a method derived by Eddy et al. (1965). Undesired high frequency oscillations are effectively eliminated and successive wind profiles show good continuity.

DD FORM 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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